Catch allocation in a shared fishery with a minimally managed recreational sector*

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Abstract

A prevalent problem in shared fisheries is competition between commercial and recreational fishers for access to a resource that is subject to increasing utilisation pressure. For most shared fisheries in New Zealand, the commercial sector is efficiently managed with a regime of individual transferable quota (ITQ), but the recreational fishing is only minimally managed.

A model is developed that can be used to explore the size of the total allowable catch (TAC) that is both sustainable AND maximises the value to the NZ economy of the combined commercial and recreational catch when the commercial catch is regulated via a total allowable commercial catch (TACC) while the recreational catch (RC) is self regulating.

Determinants of the optimal catch allocation include:

- the relative size of annual value to recreational fishers vis-à-vis the value of one unit of ACE to the commercial fishing sector from a unit decrease in the TACC
- the relation between value to recreational fishers and size of stock biomass
- the biology, and in particular the population dynamics of the fishery
- the nature of the functional relationship between the self regulating recreational catch and stock biomass.

The model can be applied to a fishery of interest by quantifying the above variables and relationships.

Introduction

Around the world, many fisheries are shared fisheries in the sense that a common fish stock is accessed by both commercial and recreational fishers[1]. Historically, the focus in fishery management has been on limiting commercial catches to ensure sustainable extraction, with other uses of fish resources, such as recreational capture and passive uses, often treated as residual activities. However, the recreational sector has continued to grow in many fisheries, putting pressure on fish stocks, so that competition between commercial and recreational fishers for access to the resource is now a prevalent problem in these fisheries. Hence, ongoing successful management of fish resources now requires the ability to make choices about the allocation of the available resource among the various competing uses. The inherent conflict surrounding allocation, and the need for formal inclusion of both commercial and recreational fishers in the decision making process has been widely recognized (Bess and Rallapudi 2007; Sutinen and Johnston 2003; Kearney 2001).

Although fishers from each sector want to catch fish, there often are significant differences in the nature of the values that they gain from doing so. While the commercial sector is focussed on maximising profits from catching fish, the motivation for recreational fishers is more complex. Specifically, the recreational fisher is best thought of as maximizing the utility or net benefit from fishing, where this incorporates both the consumption value of retained catch, and experiential components, as well as the opportunity cost of time. Determinants of the former might include species, size and catch rate, while the latter also might encompass benefits associated with the broader fishing experience, including sporting and social benefits.

While the relationship between stock abundance and value of the catch will be approximately linear for the commercial sector, it is more likely that this relationship will be acutely non-linear for the recreational sector. To improve aggregate value obtained by all stakeholders as a result of allocation decisions, it is important to clarify the nature of the relationship between catch allocation and the different values sought by the respective sectors from their participation in fishing. In doing so, it needs to be recognized that politically driven constraints on management mechanisms exist in most shared fisheries, and this further complicates the issue of dividing the "available catch" between sectors.

Using New Zealand as a reference point, this paper explores some of the general issues that managers who are charged with the task of maximizing the value to society from multiple uses of a sustainable catch need to consider when allocating a total allowable catch (TAC) between competing interests.

The New Zealand framework

Under current management arrangements for most shared fisheries in New Zealand, the commercial sector is effectively and efficiently managed with a regime of individual transferable quota (ITQ) for almost all species. However, the non-commercial sector, comprising both Maori customary fishers and recreational fishers, is only minimally managed.

Management of the commercial sector is based on the quota management system (QMS): a proportional ITQ based regime. Under this scheme, a fixed total quantity of tradable quota

[1] It is not uncommon for a fish stock to be shared between commercial fishers, recreational fishers, and customary fishers. In New Zealand, the latter two sectors are often referred to as non-commercial fishers. For heuristic simplicity, the analysis in this paper is limited to shared fisheries that only include a commercial sector and a recreational sector.

shares is held by individuals and firms for each fish stock. A total allowable commercial catch (TACC) applies to each stock and this may be varied annually by a decision of the Minister of Fisheries. These TACCs are set in advance of the start of the fishing year, at which point each ITQ shareholder's annual catch entitlement (ACE) for the coming year is determined and issued. ACE is the currency used by fishers during the year to cover catch, and can be freely traded independently of the long-term ITQ.

The catch allocation process starts with setting an overall total allowable catch covering all sectors that is set with regard to the biological state of the stock so as to satisfy the statutory objective to manage stock biomass at or above the level that will produce maximum sustainable yield (MSY).

In setting the TACC, the Minister of Fisheries must have regard to the TAC, and must also allow for Maori customary and non-commercial interests. Hence, the allocation of the TAC between commercial and non-commercial sectors is achieved by estimating the self regulating level of the non-commercial catch, and then setting the TACC to ensure that realised total catch does not exceed the TAC. This is the primary tool in the system for allocation of catch.

The non-commercial sector remains largely undifferentiated by the management system in terms of the broad range of activities carried out, and values sought. These fishers are not registered or licensed, do not report catch, and have little input into management decision-making outside of general public consultation processes." (Connor 2006).

Recreational fishing is subject to a set of general fishing regulations that can prescribe a range of measures such as minimum fish size and bag limits, gear and method restrictions, and area and season closures. Legally, the Minister is expected to use these tools to constrain the recreational catch, but in practice they are rarely so used, and in practice there are few if any limits on individual's fishing effort. Nor are there restrictions on participation rates by recreational fishers.

A key point of difference between the sectors is that commercial stakeholders have quantified rights and obligations, and are registered along with these rights in the management system. By contrast, there is no direct connection between the recreational fishing sector and the system of management.

Figure 1 illustrates the standard economic interpretation of how to maximise total net economic benefits from a shared fishery. The vertical axis shows marginal net economic value for the commercial and recreational sectors. The horizontal axis shows the total allowable catch to be shared among these two competing uses. The possible commercial and recreational fishing shares run in opposite directions, such that at any point along the horizontal axis, the sum of the two shares equals the total allowable catch. Maximum value is achieved by allocating the defined total allowable catch between commercial and recreational fishing activities so as to equate the marginal net benefit from each of the competing uses (Edwards 1990).

If the current allocation is at Z, where the marginal net benefit from recreational fishing (MBrec) exceeds the marginal net benefit from commercial fishing (MBcom), reallocating some of the total allowable catch to the recreational sector would increase the "value" of the fishery. The most efficient allocation, occurs where the marginal net economic benefits for the competing uses are equal, illustrated in the diagram at point 'T'.

A review of the standard economic approach to catch allocation

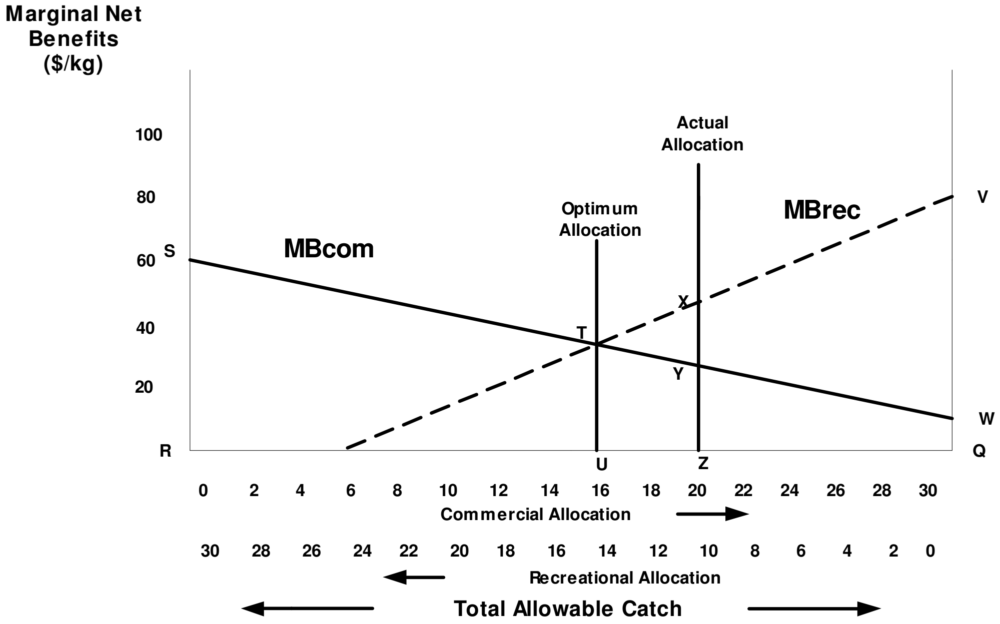

FIGURE 1. Optimal allocation of fish resource between recreational and commercial fishing

The validity of this widely accepted conceptual framework for the analysis of optimal resource allocation depends upon certain tacit assumptions, including:

- there are binding catch limits on both the commercial and recreational sectors
- there is no unused or latent capacity to increase catch
- management of both sectors ensures that the commercial and recreational catch are caught in the most cost effective manner possible

An important implication of the above is that, as for the commercial sector, the recreational sector would have a defined catch which would be caught efficiently, and would be managed so as to achieve the most efficient intra sectoral catch allocation[2]. If there is sub optimal management in either or both sectors, then the marginal benefit curves will be lower than they could be, and the inter sectoral catch allocation specified by equating marginal benefits in each sector in the conventional model will not necessarily be optimal. In extremis, if catch in one sector is not restricted, then resource rent is likely to be dissipated in the non-restricted sector.

Catch allocation in a shared fishery with asymmetric management

While the conventional model is based on efficient management in each sector, the political reality is usually different. In most fisheries, the socially and politically acceptable methods available to manage recreational fishing effort and/or catch are less effective than those deployed in the commercial fishery. Consequently, most recreational fisheries effectively approximate open access fisheries. Because there is no limitation on entry and participation, and often no requirement to even hold a fishing licence, there are no effective controls on aggregate effort and/or catch. Under these minimal management regimes, recreational catch is self regulating, and recreational fishing effort can continue to grow as population, income, and leisure time increase.

[2] For some fisheries, one way to do this might be to have tradable fish tags where the number of tags defined the recreational allocation, and new fishers could enter the fishery by buying tags.

There are two important implications of this asymmetry in the management of two sectors in a shared fishery. First, the ability to set the size of the commercial catch is the only effective policy instrument available to a fishery manager to achieve two policy targets, namely a TAC that meets sustainability objectives, and an inter-sectoral catch allocation that maximises the value of the combined catch from the two sectors.

As a result, fishery managers are unlikely to have effective means at their disposal to reallocate a specified part of the total allowable catch from the recreational fishing sector to the commercial fishing sector. Furthermore, total allowable catch can only be reallocated in the opposite direction indirectly by reducing the total allowable commercial catch, and then waiting for recreational fishers to respond to a gradual increase over time in fish stock abundance. Given the indirect nature of this resource reallocation mechanism, there is no guarantee that any eventual increase in the recreational catch will exactly offset the reduction in the commercial catch. Moreover, there will be significant time lags between the cut in the commercial catch and any increase in the recreational catch. Consequently, many of the combinations of commercial catch and recreational catch depicted in Figure 1 above will not be achievable.

Second, while inter sector allocation decisions need to be explicitly based on the marginal values of the fish resource in each of the alternative uses, there needs to be conceptual clarity about the nature of marginal values to the commercial and recreational fishing sectors. In particular, the way these are influenced by the allocation process needs to be understood. For the type of shared fishery being discussed here, the marginal value of the recreational catch cannot be elicited by asking recreational fishers questions pertaining to the value of catching an extra fish because any attempt to reallocate catch from commercial fishers need not result in an increase in catch by recreational fishers. Conceptually, there are two interrelated questions that need to be addressed, namely for a given reduction in the TACC, what is the reduction in the present value of the commercial catch, and what is the associated increase in the present value of the recreational catch.

While there are challenges in measuring net economic benefit for the commercial sector, conceptually “economic value” is derived from the tastes and preferences of consumers, and is measured in terms of ‘willingness-to-pay’ for catch entitlements. In fisheries managed by ITQs, this can usually be inferred from analysis of market data on the value of annual catch entitlement (ACE), although allowance would need to be made for changes over time in ACE values consequential on changes in stock biomass, and hence in catch rates, as a result of the transfer process.

Arguably, greater challenges arise in measuring net economic benefit for the recreational fishing sector. Recreational fisheries differ from commercial fisheries in several important respects, including; the multi dimensional nature of recreational fishing, the lack of markets for the outputs from recreational fishing, the fact that some forms of recreational fishing result in less than 100% mortality of landed catch, and political constraints on acceptable management methods for recreational fisheries. First and foremost, in contrast to commercial fisheries where the value of the retained catch normally is the sole benefit derived by fishers, recreational fishing is a more complex multi dimensional activity. Individual fishers may differ in the extent to which they derive benefits from the retained catch relative to the sport value of landing and releasing fish, and the experiential value from time spent on or adjacent to the marine or freshwater environment. Moreover, fish size, catch rate, time and place, and preferred species are all important determinants of the value to recreational fishers that tends to produce a conflict of interest with the commercial objective of simply maximising yield. (Connor 2006). The relative importance of these components of possible benefits from recreational fishing can be shown to influence the effectiveness and efficiency of different fishery regulations, as well as the marginal value to recreational fishers of an increase in stock abundance due to the reallocation of a part of the commercial sector total allowable catch (TACC) to the recreational fishing sector.

An illustrative analysis of sustainable outcomes in shared fisheries

In this section, the relationship between sustainable steady state levels of stock biomass and feasible catch allocations in a shared fishery with a minimally managed recreational sector are explored.

In a minimally managed recreational fishery, because fishing effort is not actively regulated, recreational catch is self regulating. Furthermore, the catch rate per unit of effort will be an increasing function of stock biomass (B_i). For the sake of simplicity, it will be assumed for the time being that recreational catch is a linear function of stock biomass[3], and a catch coefficient (φ) will define the rate of change in recreational catch as stock biomass changes.

Let B^* be the level of stock biomass at which the recreational catch equals the sustainable yield (SY) for the shared fishery. Obviously, for $B_i>B^*$, unregulated RC would be unsustainable, and stock biomass would decrease until it equals B^*. Hence, sustainable recreational catch (SRC) will be defined by:

$$\begin{aligned} SNCC &= \varphi * B_i \quad \text{if } B_i < B^* \\ &= SY\left(B^*\right) \quad \text{elsewise} \end{aligned} \tag{1}$$

The relationship between SY, SRC, sustainable commercial catch (SCC), and stock biomass for a hypothetical fishery is illustrated in Figure 2. SY shows the sustainable yield at each level of biomass from 0% to 100% of B_0. Note that B_{msy} is assumed to be 22% of B_0, and that MSY at this point is 10,000. SRC increases with biomass as B_i increases from zero to B^* as per equation 1. RC reaches a maximum at B^*, which is at about 65% of B_0. Beyond this point, commercial catch must be zero if the fishery is to be sustainable. In other words, sustainable commercial catch is zero for $B_i>B^*$, and the whole SY is devoted to the recreational sector. For $B_i<B^*$, SCC will equal the difference between the fishery SY and SRC.

In New Zealand, B_{msy} is essentially an environmental bottom line, because under the Fisheries Act 1996, the minister has a statutory objective to manage stock biomass at or above the level that will produce maximum sustainable yield (MSY). Hence, the problem facing the fishery manager is to aim for the level of biomass, $B^\#$, within the range $B_{msy}<B^\#<B^*$, that maximises the combined value of the commercial and recreational catch.

In practice, to achieve a desired steady state stock biomass, $B^\#$, the fishery manager would need to select the sustainable commercial catch level that is consistent with $B^\#$ and allow the fishery to adjust to $B^\#$ over time. For example, if in Figure 2, the current biomass was B_{msy}, and the desired level of biomass was B^*, then the manager would need to set the TACC to zero. Initially, the recreational catch would be less than MSY, so stock biomass would increase over time until it reached B^*. Conversely, if the current biomass was B^*, and the desired level of biomass was B_{msy}, then the manager would need to set the TACC at the sustainable commercial catch level at B_{msy}. Total catch initially would exceed sustainable yield, and stock biomass would decrease over time to B_{msy}.

[3] As discussed below, this implies that recreational fishing effort is invariant with respect to stock biomass so long as catch is proportional to the product of effort and stock biomass.

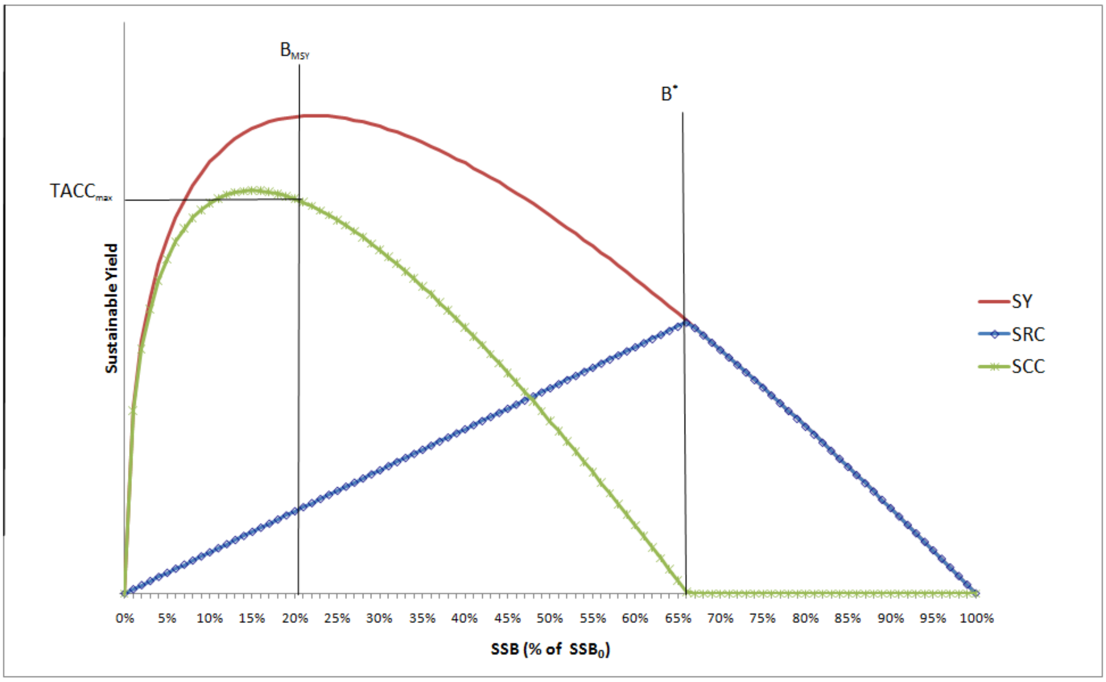

FIGURE 2. Sustainable yield and sustainable recreational catch as a function of stock biomass

The analysis embodied in Figure 2 centres around the relationship between SRC and biomass. Clearly, it is important to have some understanding about the nature of this functional relationship between the self regulating recreational catch and stock biomass, including whether this relationship is linear or not. Recreational catch is the product of recreational fishing effort and the catch rate per unit of effort, both of which are likely to be a function of stock biomass. Catch rate is often assumed to be a linear function of stock biomass, but it is more likely to increase at a diminishing rate.

It is often asserted that recreational fishers value both catch rate and the size of fish caught, and since both are likely to increase as stock biomass increases, many recreational fishers in a minimally managed fishery are likely to increase effort if stock biomass increases. However, the actual response to a biomass increase is likely to vary according to the circumstances of the fisher. Where the sole purpose of the recreational fisher is to catch a set amount of fish, or for a fisher who stops at the bag limit, effort might decrease if stock biomass increases. Where a fisher is currently stopping at less than the bag limit because either size or catch rate do not justify further effort, an increase in biomass may induce an increase in effort. There may also be an increase in participation as biomass increases. The mix of fisher characteristics and circumstances will determine the catch coefficient (φ) for a fishery, and whether it increases, is invariant, or decreases as stock biomass increases.

Different fisheries will have different values for the catch coefficient φ. They may have a different mix of fisher types but even for a given mix of fisher types, some fisheries are simply more productive at any given biomass. The effects of differences in the catch coefficient are illustrated in Figure 3 which illustrates the sensitivity of sustainable yield and sustainable recreational catch functions to catch coefficient, φ. It shows the relationship between SY, SRC, SCC, and stock biomass for two hypothetical fisheries, differentiated only by the size of a constant catch coefficient, φ.

For the higher catch coefficient fishery (SRC^{50}), B^{*50} is the biomass at which the unregulated recreational catch biomass equals the sustainable yield biomass. At this point the commercial catch allocation is zero. For the lower catch coefficient fishery (SRC^{25}), B^{*25} is the biomass at which the unregulated recreational catch biomass equals the sustainable yield biomass. Again at this point the commercial catch allocation is zero. However, with the lower catch coefficient, φ, the range of non zero commercial catch allocations is greater. Commercial catch allocation is positive up to a biomass index of around 65% compared to around 48% for the higher catch coefficient case.

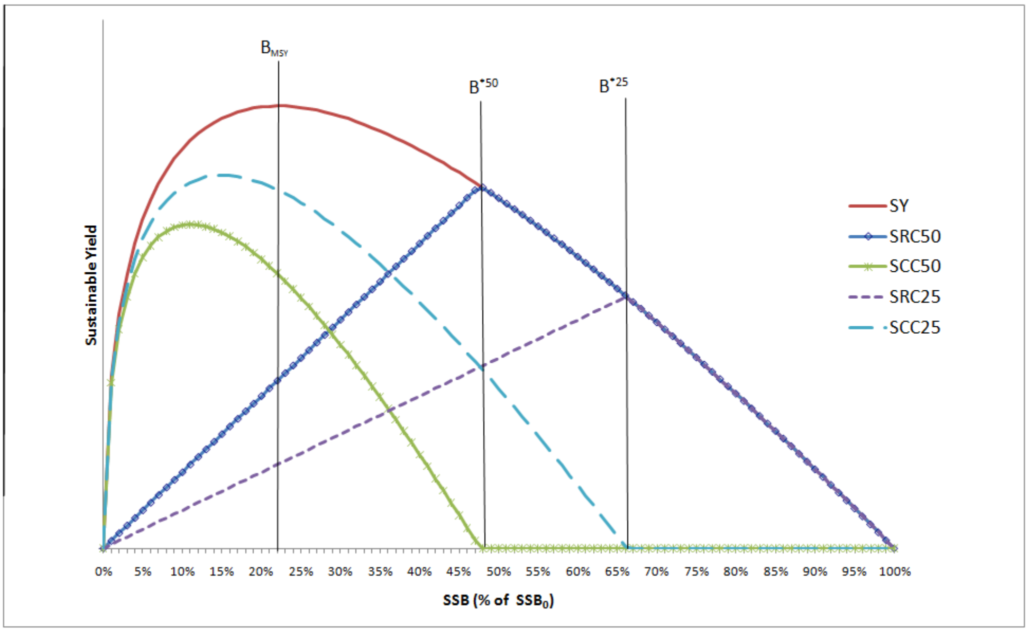

FIGURE 3. Sensitivity of sustainable yield and sustainable recreational catch functions to catch coefficient, Φ.

Figure 3 makes clear the way that recreational behaviour with respect to changes in the biomass impact upon the allocation to the commercial sector in the case where the recreational sector is minimally managed.

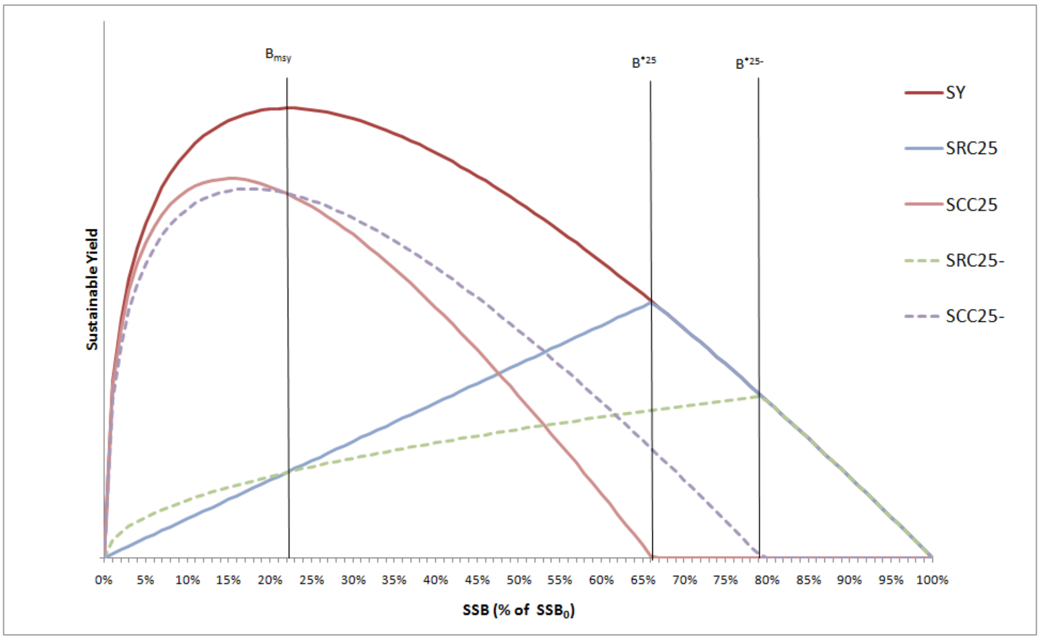

FIGURE 4. Sensitivity of sustainable yield and sustainable recreational catch functions to a diminishing catch coefficient, Φ.

Lastly, two cases where the catch coefficient, φ, does vary with stock biomass are illustrated in Figure 4 and in Figure 5. Figure 4 illustrates the case where φ declines as stock biomass increases, while Figure 5 illustrates the converse case where φ increases with increasing stock biomass.

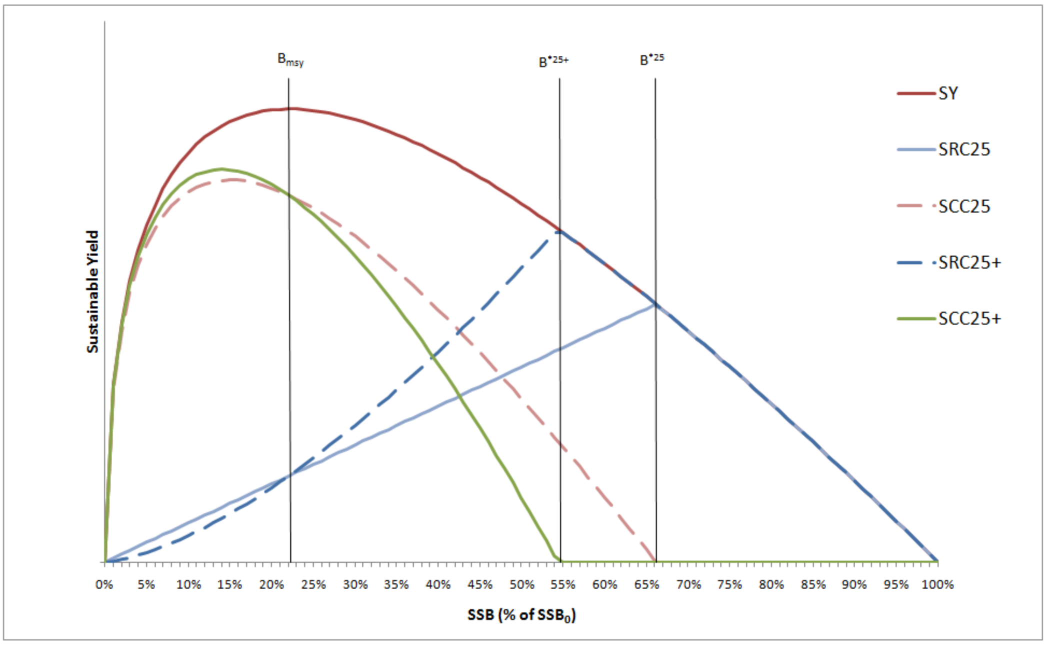

FIGURE 5. Sensitivity of sustainable yield and sustainable recreational catch functions to an increasing catch coefficient, Φ.

For the diminishing catch coefficient case (Figure 4) the biomass at which the unregulated recreational catch biomass equals the sustainable yield biomass increases whereas for the increasing catch coefficient case (Figure 5) it declines, compared to the constant catch coefficient case.

Effect of alternative catch allocations on the total economic value from a shared fishery

This section presents some illustrative analysis of how alternative catch allocations might affect the total economic value from a shared fishery with a minimally managed recreational sector.

The focus of the conventional allocation model described above was to allocate a defined total catch, typically MSY, between the commercial fishing sector and the recreational fishing sector so as to maximise the economic value of the harvest. Figure 2 to Figure 5 above illustrate the range of acceptable TACC for shared fisheries with a minimally managed recreational sector where the objective is to achieve a sustainable yield whilst having a biomass greater than or equal to B_{msy}. They do not address the question of which TACC and associated level of stock biomass within the acceptable range will maximise the economic value to the NZ economy of the combined catch.

The sustainable total economic value from a shared fishery equals the product of the sustainable commercial catch by its unit value plus the product of the sustainable recreational catch by its unit value. For many fisheries where catch is internationally traded, the unit value of the commercial catch is exogenously determined and independent of the size of the catch, so catch value will be a linear function of catch size. In New Zealand, the ACE value for commercial catch under the QMS provides an observable and objective measure of the unit value of the commercial catch. However, as discussed above, there is typically no comparable market based measure of the unit value of the recreational catch, and values have to be inferred from non-market based studies.

The key determinant of the sustainable total economic value as a function of stock biomass size is the unit value of the recreational catch relative to the unit value for the commercial catch.

The simplest possible case is where both the commercial catch and the recreational catch have the same unit value. In the analysis below this is nominally set at $1. We further assume that this value is constant, and does not change with either catch size or the level of stock biomass. The result is illustrated in Figure 6, where the curves CC$, NC$, and TC$ depict the value of the commercial catch, the value of the recreational catch, and the value of the total catch respectively. Predictably in this case, the position and shape of the sustainable economic value curves in Figure 6 are identical to the sustainable catch curves in Figure 2, and sustainable value is maximised at B_{msy}.

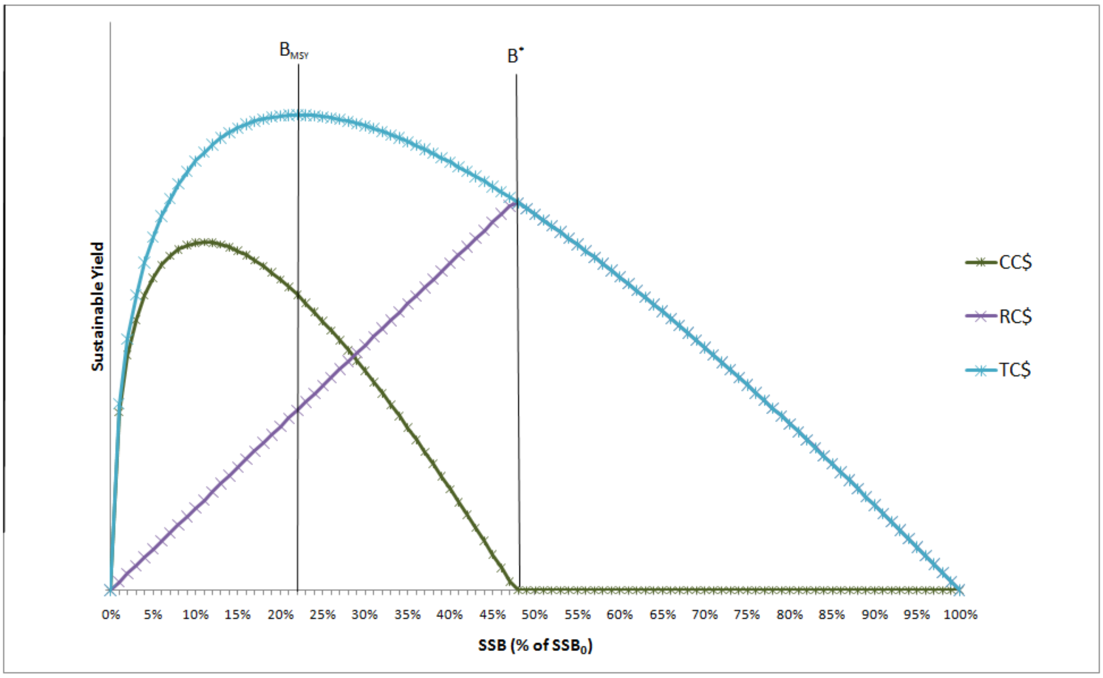

FIGURE 6. Optimal economic allocation when commercial and recreational catch have the same unit value

The more interesting and relevant case is a shared fishery where the unit value of the recreational catch is different from that of the commercial catch. For purposes of illustrating this case, first consider a scenario in which the unit value of recreational catch is half that of the unit value for commercial catch.

In Figure 7, curve $NC\$^{0.5}$ depicts the value of the recreational catch when unit value of recreational catch is half that for the commercial catch, and the curve $TC\$^{0.5}$ depicts the corresponding value of the total catch. Note that up to B*, total value is the sum of commercial and recreational catch values. Beyond B*, commercial catch is zero and the catch value reflects the value of only recreational catch.

It can be seen that while total economic value is maximised at a biomass level less than B_{msy}, taking account of the sustainability constraint means maximum sustainable total economic value is achieved at B_{msy}. This stock level will be referred to as a (lower bound) corner solution, because even though total economic value would be greater at a smaller stock level, smaller stock levels are inadmissible under New Zealand fishery legislation.

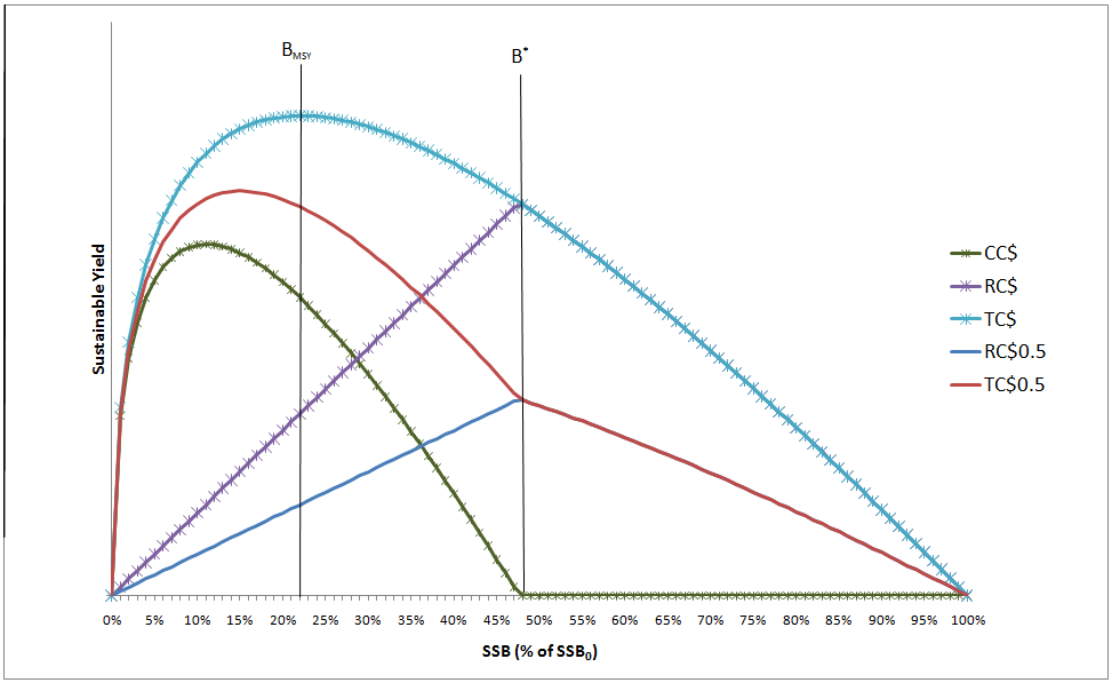

FIGURE 7. Optimal economic allocation when recreational catch unit value is 50% of the commercial catch unit value

The result illustrated in Figure 7 is a general result, and applies to any shared fishery where the unit value of the recreational catch is less than that for the commercial catch provided that both values are constant at all catch levels.

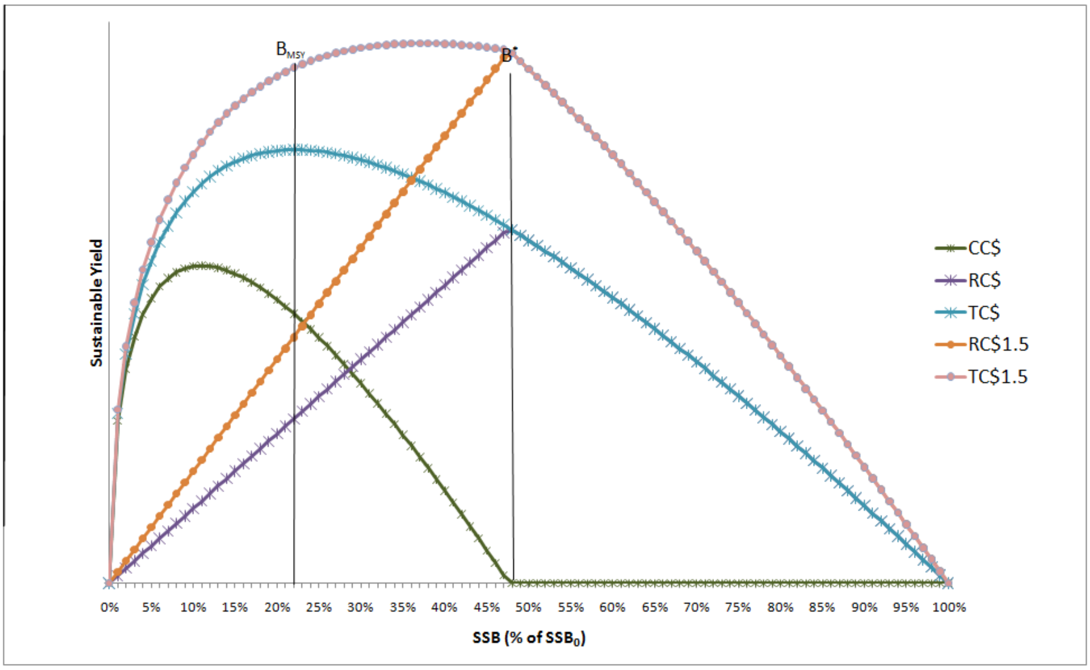

FIGURE 8. Optimal economic allocation when recreational catch unit value is 150% of commercial catch unit value

The converse case where the unit value of the recreational catch is 50% greater than that for the commercial catch is illustrated in Figure 8, where curve NC$^{1.5}$ depicts the value of the recreational catch when unit value of recreational catch is 50% greater than that for the commercial catch, and the curve TC$^{1.5}$ depicts the corresponding value of the total catch. For this case, and in general whenever the unit value of the recreational catch is appreciably greater than that for the commercial catch, the level of stock biomass at which sustainable total economic value is maximized will be greater than B_{msy}. In the case illustrated, sustainable economic value is maximized at a biomass level between B_{msy} and B^*, which is referred to as an interior solution. However, if the unit value of the recreational catch is sufficiently high relative to the unit value of the commercial catch, it can be shown that sustainable total economic value will be maximized at B^*, which is an (upper bound) corner solution.

Another key issue is whether the unit value of the recreational catch is a linear function of catch size (and stock biomass level), or whether unit value actually increases as the level of the stock biomass increases. A case can be made that the latter assumption is more realistic for many shared fisheries. This argument is based on the view that recreational fishers value both catch rate and the size of fish caught. Hence, they would place a higher unit value on catch where the catch rate was higher and the average size of fish caught was larger. As both catch rate and average fish size caught are likely to increase as stock biomass increases, then unit value for recreational catch is likely to increase with biomass. This increasing unit value applies even when the underlying catch coefficient, φ, is constant. Figure 9 illustrates such a case.

In Figure 9, unit value for the commercial catch is \$1, but unit value for the recreational catch = $\$(1+B_i/B_0)$. The corresponding value of the recreational catch and the total catch are depicted by curves $NC\$^+$ and $TC\$^+$ respectively. Unlike the previous case in which sustainable economic value was maximized at a biomass between B_{msy} and B^*, in Figure 9 the biomass that maximizes economic value is B^*. This occurs because over the range B_{msy} to B^*, the unit value for recreational fishing is increasing relative to the unit value of commercial fishing, which has the effect of increasing overall economic value as commercial allocation is reduced and recreational allocation increases. As in previous illustrations, once the commercial catch is reduced to zero at B*, future economic value follows the path of recreational catch and biomass.

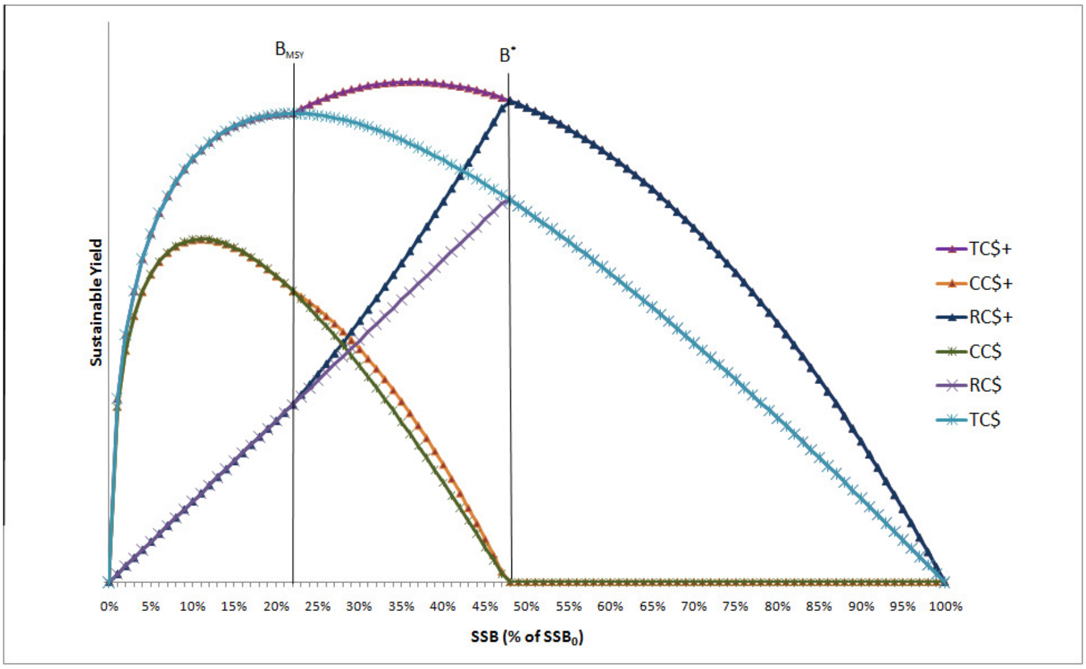

FIGURE 9. Optimal economic allocation when recreational catch has increasing unit value

Figure 9 has an increasing unit value for recreational fishing with the recreational starting unit value being equal to the unit value for commercial catch. If the starting value for recreational value exceeded that for commercial catch the result in Figure 9 would be reinforced. The optimum recreational catch biomass B* would prevail with optimal commercial catch equal to zero.

However, if the starting value for the recreational catch is less than that for commercial catch, the result might be as illustrated in Figure 10 where unit value for the commercial catch is $1, but unit value for the recreational catch = $\$(0.1+B_i/B_0)$. In this case, the optimal sustainable stock biomass equals B_{msy}. Essentially, if the recreational unit value is well below the commercial catch unit value, it doesn't increase enough with biomass to offset the value foregone with the reduction in commercial catch that occurs to accommodate the growth in recreational catch and maintain the SY biomass. In this case the maximum economic value is maximised at a stock biomass level less than B_{msy}, which means that, taking account of the sustainability constraint, maximum sustainable total economic value is achieved at B_{msy}.

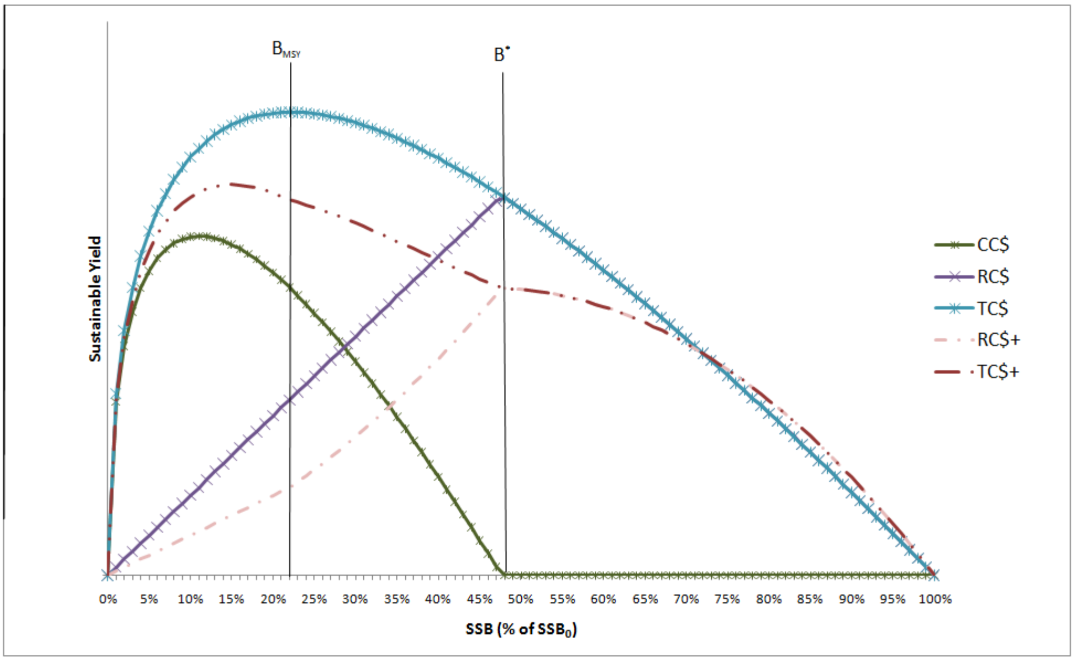

FIGURE 10. Optimal economic allocation when recreational catch has increasing unit value and a starting value below commercial catch value

Conclusions

In a minimally managed fishery, recreational fishing effort is at most lightly regulated, so recreational catch (RC) essentially is self regulating. Recreational fishers may respond to improvements in biomass by increasing effort per fisher, and/or by an increase in fisher participation. Furthermore, the catch rate per unit of effort will be an increasing function of stock biomass (B_i). By contrast the commercial sector has limited entry and well defined and binding catch limits. This asymmetry results in control of the control commercial catch being the only instrument used to achieve both a sustainable harvest outcome and an optimal allocation of that harvest.

In this case, at any given biomass level, the sustainable regulated TACC is effectively a residual equal to the difference between the overall fishery sustainable yield, and sustainable recreational catch at the level of stock biomass, B^i. Because, recreational effort increases with biomass, at some point the sustainable recreational catch equates to the whole of the sustainable yield biomass, and the optimal commercial allocation is zero

The behaviour of recreational fishers as biomass changes, and the relationship between unit values of commercial and recreational fishing, are the keys to understanding management strategies in this situation.

The implications for catch allocation between the commercial and recreational sectors of various assumptions regarding these two variables have been demonstrated above by documenting the relationship between sustainable yield biomass and the relative sustainable commercial and recreational catch using a model where the sum of the two must equate to the sustainable yield biomass.

The starting point for the analysis was a model of the range of acceptable TACC for shared fisheries with a minimally managed recreational sector where the objective is to achieve a sustainable yield whilst having a biomass greater than or equal to B_{msy}.

The model illustrates the way in which the biomass at which recreational catch equals the whole of the sustainable biomass depends on the magnitude of the recreational catch coefficient. Assuming a constant catch coefficient, the larger the catch coefficient, the lower the biomass at which the unregulated recreational catch biomass equals the sustainable yield biomass, and commercial catch allocation goes to zero.

Beyond the simplistic assumption of constant coefficients, it is possible that the behaviour of recreational fishers with respect to biomass would result in the catch coefficient either increasing or decreasing at the margin as biomass increases. The model results indicate that if the recreational catch coefficient is increasing, the biomass at which the unregulated recreational catch biomass equals the sustainable yield biomass is reduced, whereas if the catch coefficient in diminishing it is increased.

In addition to simulating the TACC consistent with having a sustainable yield biomass greater than or equal to B_{msy}, there is the further question about the level of the TACC and associated biomass that will maximize the economic value of the combined recreational and commercial harvests.

These simulations illustrate that the key drivers of this outcome are relative unit values for recreational catch and commercial catch, and the way that these catch values change as biomass increases. Two cases are developed, one where the unit value of recreational catch is below that of the unit value for commercial catch and one where it is higher.

In the case where unit value of recreational catch is half that of the unit value for commercial catch, total economic value is maximised at a stock biomass level less than B_{msy}, This means that taking account of the sustainability constraint means maximum sustainable total economic value is achieved at B_{msy}. This can be regarded as a general result and applies to any shared fishery where the unit value of the recreational catch is less than that for the commercial catch.

For the case where the unit value of the recreational catch is 50% greater than that for the commercial catch, the level of stock biomass at which sustainable total economic value is maximized is greater than B_{msy}. Again this can be regarded as general outcome whenever the unit value of the recreational catch is greater than that for the commercial catch, If the unit value of the recreational catch is sufficiently high compared to the unit value of the commercial catch maximum economic value arises where the TACC is equal to zero.

The recreational catch value may be increasing or decreasing with respect to the level of stock biomass. In the case where it is increasing the biomass that maximizes economic value occurs where recreational catch is equal to the sustainable yield harvest and the TACC is zero. In this case if the initial unit value for the recreational catch exceeds that of the commercial catch the result I strengthened. However, if the initial unit value for the recreational catch is below that of the commercial catch the total economic value is maximised at a stock biomass level less than B_{msy}, This means that taking account of the sustainability constraint means maximum sustainable total economic value is achieved at B_{msy}.

To sum up, it is common in shared fisheries for the commercial sector to be tightly controlled, while the recreational sector is lightly regulated, so setting the TACC is the only regulatory instrument available to fishery managers to achieve sustainable harvest and/or optimal catch allocation. In the analysis presented above, the range of possible outcomes for such shared fisheries was illustrated, and it was shown that the relative recreational and commercial catch unit values, and the way the level of recreational catch as well as its value are influenced by changes in biomass, are the critical variables that affect the outcome.

The optimal level of the TACC for a specific shared fishery where recreational catch is minimally managed will depend on the particular dimensions of the fishery, including the sustainable yield curve, the relative unit values for the commercial and non commercial catch, and the relationship between biomass and the level of recreational catch and its unit value.

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